



Acid Base Disorders



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Objectives

- To provide a simple, systematic approach to interpreting arterial blood gas (ABG) samples.

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- Multiple formulas and rules exist to help guide us through the forest of diagnoses and complex problems
 - All that is needed is a little clinical information obtained from a history and physical examination, a few readily available laboratory tests, and the knowledge of five simple steps.

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- ▶ Getting in the routine of performing these steps on each patient in which an ABG and electrolytes are performed will help decrease the rate of missed complex acid-base disturbances and hopefully improve patient care

Five Steps of Acid-Base Analysis 1-5

- ▶ **Step 1:** Acidemia (pH <7.38) or alkalemia (pH >7.42)?
- ▶ **Step 2:** Primary respiratory or metabolic disturbance? (Look at PCO₂ on ABG or HCO₃ on metabolic panel.)
- ▶ **Step 3:** Is there appropriate compensation for the primary disorder?
 - Metabolic acidosis: $PCO_2 = [1.5 \times (\text{serum HCO}_3)] + 8 (\pm 2)$
 - Metabolic alkalosis: $\uparrow PCO_2 = 0.6 \times \uparrow HCO_3 (\pm 2)$
 - Respiratory acidosis: $\uparrow PCO_2$ 10, $\uparrow HCO_3$ by 1 (acute) or 4 (chronic)
 - Respiratory alkalosis: $\downarrow PCO_2$ 10, $\downarrow HCO_3$ by 2 (acute) or 5 (chronic)
- ▶ **Step 4:** Is there an anion gap metabolic acidosis (AGMA)? $AG = Na - (HCO_3 + Cl)$. If > 12, an AGMA is present.
- ▶ **Step 5:** If metabolic acidosis, is there another concomitant metabolic disturbance?
If AGMA, then calculate $\Delta Gap = \Delta AG - \Delta HCO_3 = (AG - 12) - (24 - HCO_3)$

If the ΔGap is > 6, there is a combined AGMA and metabolic alkalosis.

If the ΔGap is < -6, there is a combined AGMA and NAGMA.

If NAGMA, for every 1 mEq/L $\uparrow Cl$, there should be a 1 mEq/L $\downarrow HCO_3 (\pm 5)$.

If HCO₃ decrease is less than predicted, then NAGMA and metabolic alkalosis.



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Five Steps of Acid-Base Analysis 1-5

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- **Metabolic acidosis:** $PCO_2 = [1.5 \times (\text{serum } HCO_3)] + 8 (\pm 2)$
- **Metabolic alkalosis:** $\uparrow PCO_2 = 0.6 \times \uparrow HCO_3 (\pm 2)$
- **Respiratory acidosis:** $\uparrow PCO_2$ 10, $\uparrow HCO_3$ by 1 (acute) or 4 (chronic)
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Five Steps of Acid-Base Analysis 1-5

- **Step 4:** Is there an anion gap metabolic acidosis (AGMA)?
- $AG = Na - (HCO_3 + Cl)$.
- If > 12 , an AGMA is present



Five Steps of Acid-Base Analysis 1-5

- **Step 5:** If metabolic acidosis, is there another concomitant metabolic disturbance?
- If AGMA, then calculate $\Delta\text{Gap} = \Delta\text{AG} - \Delta\text{HCO}_3 = (\text{AG} - 12) - (24 - \text{HCO}_3)$
- If the ΔGap is > 6 , there is a combined AGMA and metabolic alkalosis
- If the ΔGap is < -6 , there is a combined AGMA and NAGMA.





Five Steps of Acid-Base Analysis 1-5

- ▶ If NAGMA, for every 1 mEq/L \uparrow Cl, there should be a 1 mEq/L \downarrow HCO₃ (± 5).
- ▶ If HCO₃ decrease is less than predicted, then NAGMA and metabolic alkalosis


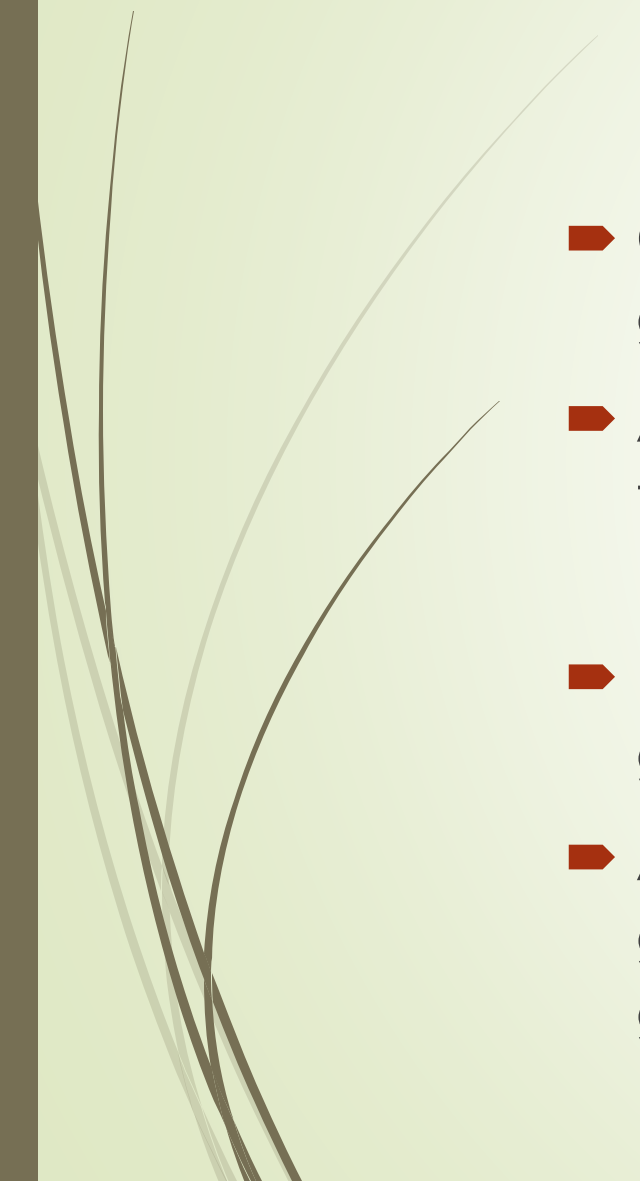




Metabolic Acidosis

- ▶ In the presence of a $\text{pH} < 7.38$, metabolic acidosis is diagnosed as a primary condition when the pCO_2 is < 40 mmHg or the bicarbonate is < 24 mEq/L.
- ▶ Metabolic acidosis can be further classified based on the presence of an anion gap.
- ▶ The anion gap reflects the balance between positively and negatively charged particles in the blood.

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- ▶ Sodium is the only significant positively charge particle that is measured, while the measured anions are chloride and bicarbonate.
 - ▶ Therefore, the anion gap is calculated by the formula:

$$\text{Na} - (\text{Cl} + \text{HCO}_3).$$

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- One potential pitfall in the measurement of the anion gap is patients with low albumin.
 - Albumin has several negative charges on it and therefore, in a patient with a low albumin level, their “normal” anion gap might be much lower than 12.
 - For every 1 gram drop in serum albumin level, the anion gap decreases by 2.5.
 - A patient with a calculated anion gap of 10 and a 2 gram drop in their albumin may actually have an anion gap metabolic acidosis (recalculated AG 15).


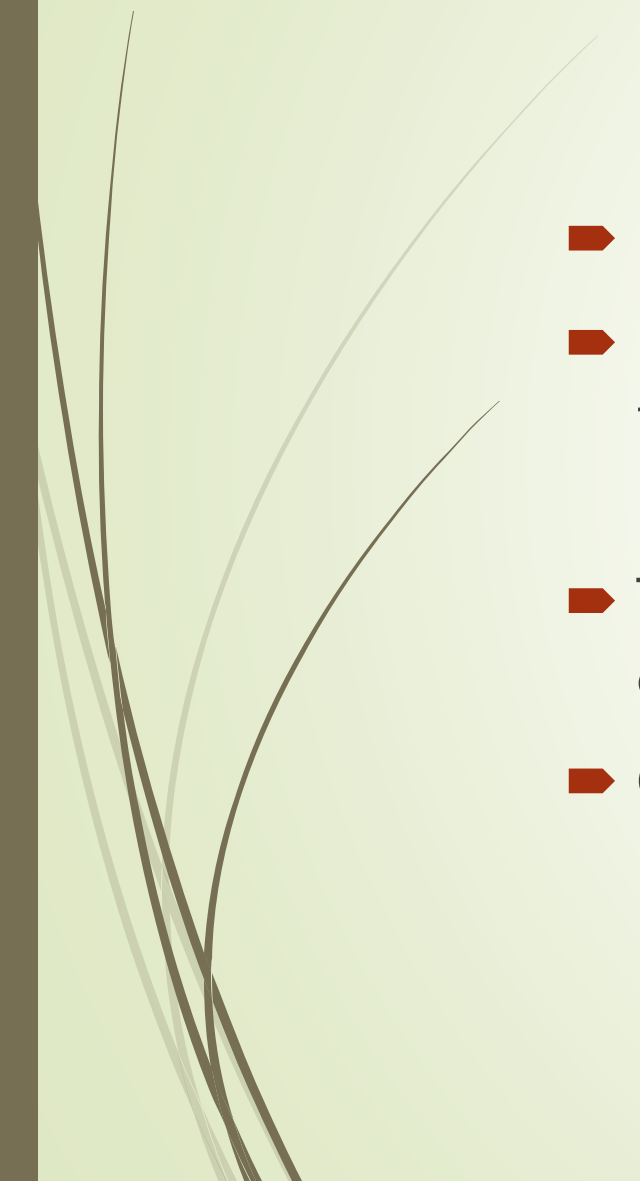
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- ▶ Anion Gap Metabolic Acidosis (AGMA) Detection of an AGMA is important because only a few conditions commonly cause it.
 - ▶ In addition, in mixed acid-base disorders, an elevation in the anion gap may be the only signal that a metabolic acidosis is present.
 - ▶ The causes of an AGMA are divided into four main categories:
 - renal failure, ketoacidosis, toxins, and lactic acidosis



Metabolic acidosis

➤ A CAT MUDPILES:

- Analgesics (massive NSAID, acetaminophen) o
- Cyanide, Carbon monoxide
- Arsenic, Alcoholic ketoacidosis
- Toluene o Methanol, Metformin o
- Uremia o Diabetic ketoacidosis
- Paraldehyde, Phenformin
- Iron, Isoniazid
- Lactic acidosis
- Ethylene glycol
- Salicylates


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- In any patient with an *AGMA*, calculate an osmol gap.
 - Osmol gaps are a clue to a potentially life-threatening toxic alcohol ingestion (ie. ethylene glycol and methanol).
 - The osmol gap is determined by subtracting the calculated osmolality from the measured osmolality.
 - Calculated osmolality = $2(\text{Na}) + \text{Glc}/18 + \text{BUN}/2.4 + \text{ETOH}/4.6$



32 year old man with depression and alcohol abuse presents with altered mental status.

➤ ABG: pH 6.9, pCO₂ 29, pO₂ 100


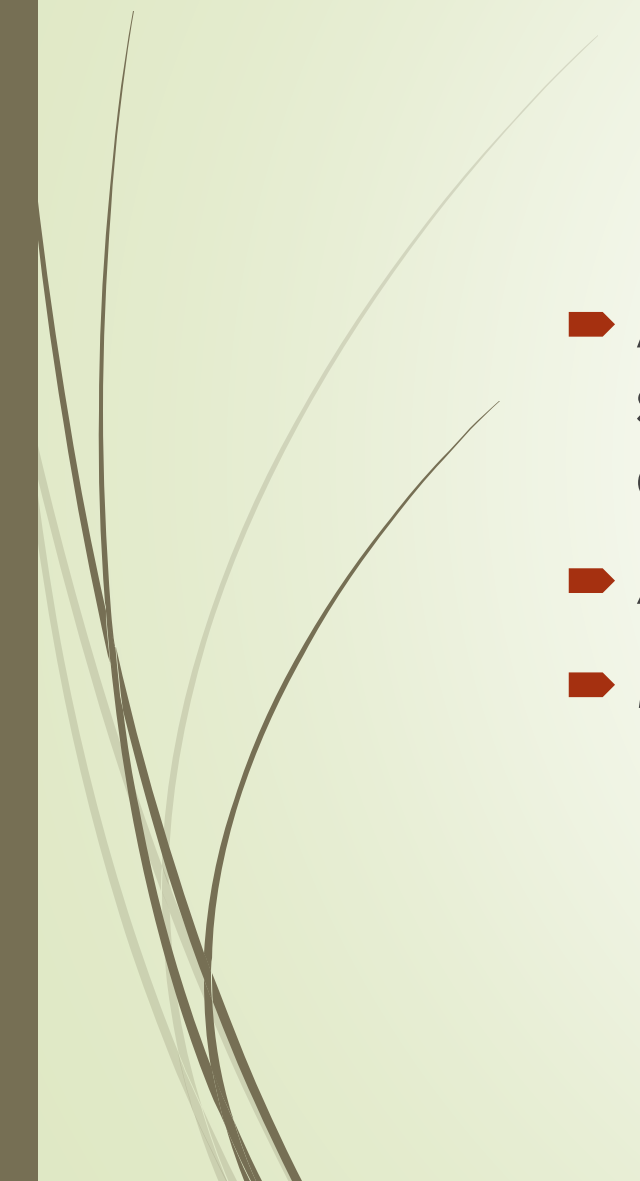
➤ Metabolic panel: Na 140, Cl 101, HCO₃ 5

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- **Step 1:** Acidosis
 - **Step 2:** Metabolic
 - **Step 3:** $p\text{CO}_2 = 1.5(\text{HCO}_3) + 8 = 15$, but the patient's $p\text{CO}_2$ is higher than 15. Therefore, a respiratory acidosis is also present, possibly secondary to CNS depression.
 - **Step 4:** $\text{AG} = 140 - (101 + 5) = 34$
 - **Step 5:** Delta gap = $(34-12) - (24-5) = 3$. No additional metabolic disorders other than AGMA.
 - **Answer: Anion gap metabolic acidosis and respiratory acidosis. The patient had an osmol gap of 174 and a methanol level of 510 mg/dL.**



Non-Anion Gap Metabolic Acidosis (NAGMA)

- A NAGMA is due to either GI or renal losses of bicarbonate.
- If desired, GI mediated and renally mediated losses can be distinguished by obtaining urine electrolytes (ie. Na, K, and Cl) and calculating the urine anion gap.
- The urine anion gap : $Na + K - Cl$
- The urine anion gap is the difference between the spot urine positive ions and spot urine negative ions.
- If an excess of negatively charged ions is present, the acidemia is due to the kidney

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- **A 68 year old man who recently took antibiotics for a skin infection presents with 10 episodes of watery diarrhea per day for the last 5 days.**
 - ABG: pH 7.34, pCO₂ 34, pO₂ 80
 - Metabolic panel: Na 135, Cl 108, HCO₃ 18



Step 1: Acidosis

➤ **Step 2:** Metabolic

➤ **Step 3:** $p\text{CO}_2 = 1.5(\text{HCO}_3) + 8 = 35$


➤ **Step 4:** $\text{AG} = 135 - (108 + 18) = 9$

➤ **Step 5:** $\text{Cl} \uparrow$ by 8 and $\text{HCO}_3 \downarrow$ by 6; therefore there is no metabolic alkalosis.

➤ **Answer: NAGMA due to diarrhea**





Respiratory acidosis


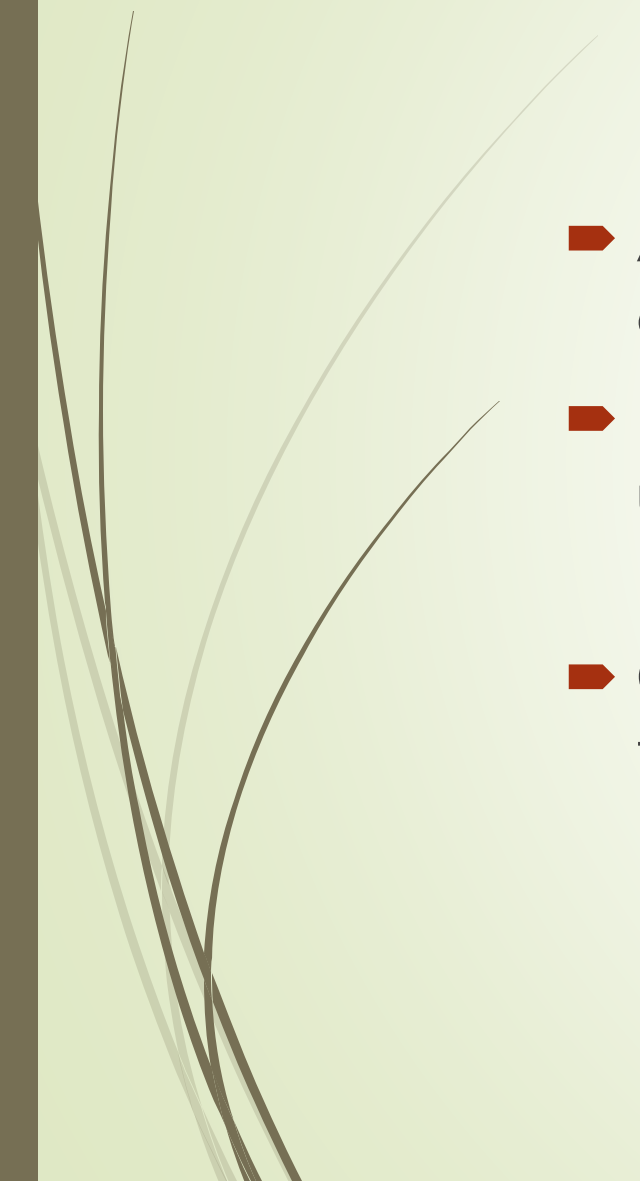
- Respiratory acidosis is characterized by an elevation in the $p\text{CO}_2$ and a decrease in blood pH due most commonly to hypoventilation.
 - It results from conditions that decrease the ability of the lungs to excrete carbon dioxide at a rate to keep up with the body's production.
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➤ **A differential diagnosis includes:**


- Central nervous system depression (sedatives, CNS disease, sleep apnea)
- Pleural disease (large pneumothorax or pleural effusion)
- Lung disease (ARDS, COPD, pulmonary edema, severe pneumonia)
- Acute airway obstruction (laryngospasm, sleep apnea)
- Neuromuscular disorders (GBS, myasthenia gravis, botulism)
- Thoracic cage injury (flail chest)
- Ventilator dysfunction

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- The kidney compensates for primary respiratory acidosis by retaining bicarbonate.
 - This compensation occurs over hours to days and is generally at a maximum within four days.
 - The rate of onset of respiratory acidosis can be determined by the degree of renal compensation (increase in HCO_3^-) as listed above in step 3.

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- Alternatively, the chronicity of the respiratory acidosis can be predicted by the change in the pH.
 - In acute respiratory acidosis, the pH decreases by 0.08 units for each increase of 10 mmHg in the pCO₂ from its baseline of 40 mmHg.
 - Chronic respiratory acidosis is marked by a decrease in the pH of 0.03 units for every increase of 10 mmHg in the pCO₂.

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- Differentiating acute from chronic respiratory conditions can have important clinical implications that may alert the clinician to a patient that is rapidly spiraling downward and might require emergent intubation, from a patient who has chronic disease, but is in less danger of imminent decompensation


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- ***A 70 year-old smoker presents with an acute onset of shortness of breath.***
 - ABG: pH 7.30, pCO₂ = 60 mmHg, pO₂ 60 mmHg
 - Metabolic panel: Na 135, Cl 100, HCO₃ 30

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- **Step 1:** Acidosis
 - **Step 2:** Respiratory
 - **Step 3:** Acute on chronic. pCO₂ increased by 20, therefore the HCO₃ should increase by 2 if acute and 8 if chronic. Because the HCO₃ increased from 24 to 30 (6), an acute on chronic respiratory acidosis is present.
 - **Step 4:** AG = $135 - (100 + 26) = 9$. No anion gap metabolic acidosis
 - **Step 5:** XX
 - **Answer: Acute on chronic respiratory acidosis due to COPD exacerbation**



Metabolic alkalosis

- Metabolic alkalosis is characterized by an increase in the serum bicarbonate concentration.
- **The causes of metabolic alkalosis are :**
- Volume contraction (vomiting, NG suction, loop or thiazide diuretics).
- Excess glucocorticoids or mineralocorticoids (eg, Cushing's syndrome).
- Hypokalemia
- Bartter's syndrome.
- Alkali ingestion/infusion.
- Post-hypercapnic alkalosis

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- To differentiate the most common cause of metabolic alkalosis which is volume depletion from other causes you need to measure urine chloride
 - If urine chloride less than 10 this due to volume depletion (saline response)
 - If urine chloride more than 10 this due to other causes (saline resistance)




➤ **Example 4:**

➤ ***A 20 year old student presents with excessive vomiting after binge drinking.***

➤ ABG: pH 7.50, pCO₂ 44, pO₂ 100

➤ Metabolic panel: Na 138, Cl 100, HCO₃ 30

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- **Step 1:** Alkalosis
 - **Step 2:** Metabolic
 - **Step 3:** Increase in pCO₂ should equal 0.6 multiplied by the elevation of the HCO₃ ±2.
 - The increase of the pCO₂ of 4 is within two of 6(0.6) or 3.6; therefore there is appropriate compensation.
 - **Step 4:** $AG = 138 - (100 + 30) = 8$
 - **Step 5:** XX
 - **Answer: Metabolic alkalosis secondary to vomiting**




Respiratory alkalosis


- ▶ Respiratory alkalosis is characterized by a decrease in the $p\text{CO}_2$ and an elevation in the blood pH.
- ▶ The $p\text{O}_2$ can be used to distinguish between disease of the lungs and other causes of hyperpnea (eg, fever)



➤ **The causes of a primary respiratory alkalosis include:**

- CNS disease (CVA) o Toxins (Salicylates)
- High altitude
- Severe anemia
- Pregnancy
- Lung disease/hypoxia (asthma, pneumonia, PE, pulmonary edema, pulmonary fibrosis)
- Anxiety o Cirrhosis of the liver
- Fever (Sepsis)
- Ventilator dysfunction

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- ***A 22 year-old woman presents with 4 hours of numbness in both hands typical***
 - of previous episodes of anxiety.
 - ABG: pH 7.48, pCO₂ 30 mmHg, pO₂ 86 mmHg
 - Metabolic panel: Na 140, Cl 110, HCO₃ 22

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- **Step 1:** Alkalosis
 - **Step 2:** Respiratory
 - **Step 3:** Acute. Drop in the pCO₂ by 10 corresponds to a drop in the HCO₃ by 2 if acute and 5 if chronic. $24 - 22 = 2$ and therefore, as would be expected by the clinical history, an acute disorder is diagnosed.
 - **Step 4:** AG $140 - (110 + 22) = 8$
 - **Step 5:** XX
 - **Answer:** Acute respiratory alkalosis secondary to a panic attack



Practice Cases

▶ **CASE 1**

- ▶ A diabetic presents with diarrhea and cough.
- ▶ CXR reveals an infiltrate.
- ▶ pH 7.31; pCO₂ 10
- ▶ Na 123; Cl 99; HCO₃ 5

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- ▶ **Primary AGMA (DKA), respiratory alkalosis (pneumonia), NAGMA (diarrhea)**



➤ **CASE 2**

➤ An alcoholic presents with vomiting.

➤ pH 7.20; pCO₂ 25

➤ Na 130; Cl 80; HCO₃ 10

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- ▶ **Primary AGMA (alcoholic ketoacidosis), metabolic alkalosis (vomiting)**



➤ **CASE 3**

- A man with arthritis presents with confusion, shortness of breath, and diaphoresis.
- pH 7.30; pCO₂ 18
- Na 147; Cl 108; HCO₃ 16

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- ▶ **Primary AGMA and respiratory alkalosis (Salicylate toxicity—107 mg/dl)**



➤ **CASE 4**

➤ A patient with COPD presents with shortness of breath.

➤ pH 7.18; pCO₂ 80

➤ Na 135; Cl 93; HCO₃ 30

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- ▶ **Primary respiratory acidosis—acute-on-chronic (COPD exacerbation)**



➤ **CASE 5**

- A woman with Crohn's disease presents with fever, vomiting, and diarrhea.
- pH 7.36; pCO₂ 22
- Na 147; Cl 121; HCO₃ 14

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- ▶ **Primary NAGMA (diarrhea), respiratory alkalosis (fever), metabolic alkalosis (vomiting)**



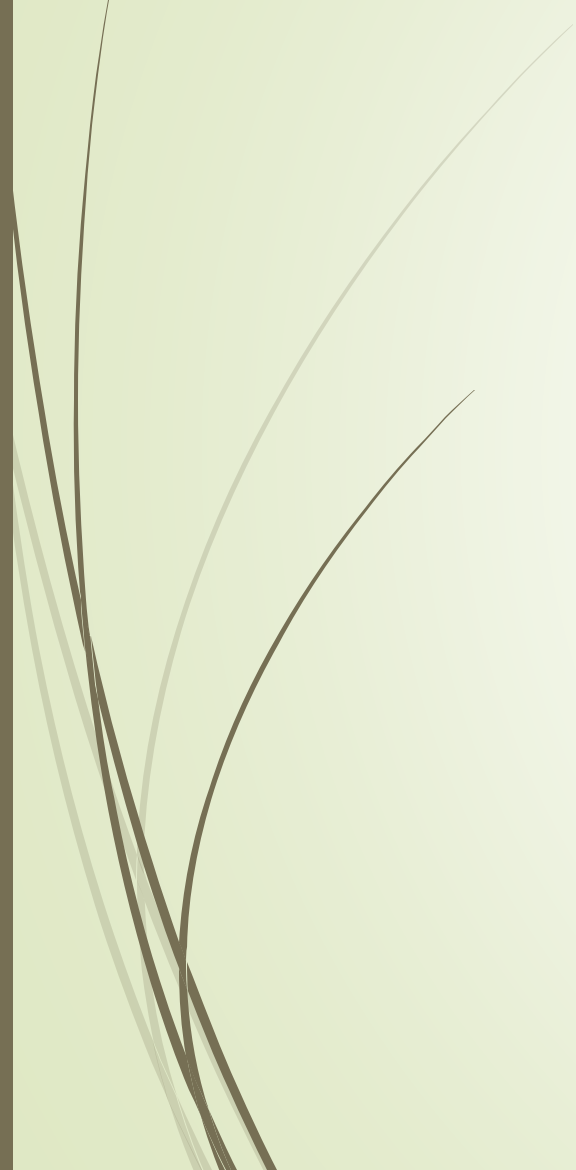
➤ **CASE 6**

➤ A noncompliant patient with diabetes and cirrhosis presents with vomiting.

➤ pH 7.46; pCO₂ 17

➤ Na 133; Cl 84; HCO₃ 15

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- ▶ **Primary chronic respiratory alkalosis (cirrhosis), AGMA (DKA), metabolic alkalosis**



QUESTION